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PRIMORDIAL R-PROCESS DISPERSION IN METAL-POOR GLOBULAR CLUSTERS

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ABSTRACT

Heavy elements, those produced by neutron-capture reactions, have traditionally shown no star-to-star dispersion in all but a handful of metal-poor globular clusters (GCs). Recent detections of low [Pb/Eu] ratios or upper limits in several metal-poor GCs indicate that the heavy elements in these GCs were produced exclusively by an r-process. Reexamining GC heavy element abundances from the literature, we find unmistakable correlations between the [La/Fe] and [Eu/Fe] ratios in 4 metal-poor GCs (M5, M15, M92, and NGC 3201), only 2 of which were known previously. This indicates that the total r-process abundances vary star-to-star (by factors of 2–6) relative to Fe within each GC. We also identify potential dispersion in two other GCs (M3 and M13). Several GCs (M12, M80, and NGC 6752) show no evidence of r-process dispersion. The r-process dispersion is not correlated with the well-known light element dispersion, indicating it was present in the gas throughout the duration of star formation. The observations available at present suggest that star-to-star r-process dispersion within metal-poor GCs may be a common but not ubiquitous phenomenon that is neither predicted by nor accounted for in current models of GC formation and evolution.

Subject headings: Galaxy: halo — globular clusters: general — nuclear reactions, nucleosynthesis, abundances — stars: abundances — stars: Population II

1. INTRODUCTION

Dispersion among the light elements (C through Al) is a nearly universal feature of stars formed in globular cluster (GC) environments. Heavier α or Fe-group elements (e.g., Ca, Ti, Fe) do not typically show any star-to-star dispersion within a given GC. A complex and precisely-tuned—yet common, apparently—sequence of events is required to produce these peculiar chemical signatures. Compared to the lighter elements, however, the elements produce by neutron (n) capture reactions ($Z \gtrsim 32$) are relatively understudied in GCs.

There are two basic mechanisms to produce nuclei heavier than the Fe-group, reactions that add neutrons to existing seed nuclei on timescales slow (s) or rapid (r) relative to the average β-decay rates of the radioactive nuclei. The main component of the s-process is associated with low or intermediate mass thermally-pulsing asymptotic giant branch (AGB) stars. Despite more than 2 decades of intense study of field stars (see the review by Sneden et al. 2008), the specific astrophysical site(s) of r-process nucleosynthesis is (are) unknown, though association with core-collapse supernovae (SNe) is likely based on the short timescales required ($\sim$ 1 s) and appearance of r-process material in extremely metal-poor stars ([Fe/H] < -3).[1]

In metal-poor GCs, r-process nucleosynthesis dominates production of the heavy elements. (e.g., Gratton et al. 2004; Roederer et al. 2010b). These elements have been observed to show no significant (i.e., cosmic) star-to-star dispersion within each GC except for a few rare cases. Some massive GCs (e.g., ω Cen) show internal spreads in their heavy elements (e.g., Ca, Fe, Ba) and may be the stripped nuclei of former dwarf galaxies (e.g., Norris et al. 1996). Individual stars on the AGB in some GCs hint of self-pollution by s-process material (Smith 2008). M15 and M92 show an unmistakable star-to-star dispersion of r-process material relative to Fe (e.g., Sneden et al. 1997; Roederer & Sneden 2011), which is uncorrelated with the light element dispersion (see also D'Orazi et al. 2010). Although the r-process dispersion in M15 has been known for more than a decade, it has not been explained. In this Letter we examine whether M15 and M92 are unique exceptions among metal-poor GCs with regard to their r-process dispersion.

2. LITERATURE DATA

We have compiled n-capture abundances for individual GC stars from a number of studies in the literature. We limit our search to metal-poor GCs ([Fe/H] < -1.0) whose [La/Fe] and [Eu/Fe] ratios have been derived in a single study in at least 5 stars. In practice 10–20 stars are necessary to reliably identify dispersion in r-process abundances relative to Fe. Some GCs have been studied by multiple investigators, and we examine their abundance correlations independently. We include data for 11 GCs from 17 separate studies, listed in Table 1. Whenever possible, ratios among species of the same ionization state are given (e.g., [Eu II/Fe II]). Typical uncertainties for [La/Fe] and [Eu/Fe] are 0.10–0.15 dex and not more than 0.20 dex in all cases (except for M92; see discussion below). Only two of these GCs, M15 and M92, are previously known to exhibit star-to-star r-process dispersion. M22 and NGC 1851 each contain a population of stars whose heavy elements were produced only by r-process nucleosynthesis and a population with an additional s-process component; we consider only the r-process population.

3. GLOBULAR CLUSTERS WITH R-PROCESS DISPERSION

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[1] For elements X and Y, [X/Y] $\equiv \log_{10}(N_X/N_Y)_\star - \log_{10}(N_X/N_Y)_\odot$.

TABLE 1
Correlations among Abundance Ratios

Cluster (References)	Ratio Pair		
	[La/Fe] + [Eu/Fe]	[La/Fe] + [Na/Fe]	[Eu/Fe] + [Na/Fe]
M3 (Sneden et al. 2004)	(0.64, 20, 0.00024)	(−0.20, 20, 0.39)	(0.12, 22, 0.60)
M3 (Cohen & Meléndez 2005)	(0.35, 7, 0.45)	(−0.21, 7, 0.65)	(−0.24, 8, 0.57)
M5 (Ivans et al. 2001)	(0.43, 25, 0.034)	(−0.25, 25, 0.22)	(−0.16, 25, 0.45)
M5 (Lai et al. 2011)	(0.80, 17, 0.00010)	(0.10, 17, 0.70)	(0.16, 17, 0.55)
M12 (Johnson & Pilachowski 2006)	(-0.31, 21, 0.17)	(−0.37, 11, 0.26)	(0.41, 11, 0.21)
M13 (Sneden et al. 2004)	(0.72, 18, 0.00066)	(−0.51, 18, 0.029)	(−0.40, 18, 0.099)
M13 (Cohen & Meléndez 2005)	(0.07, 11, 0.83)	(−0.23, 12, 0.47)	(0.43, 12, 0.16)
M15 (Otsuki et al. 2006)	(0.97, 6, 0.0011)	···	···
M15 (Sobeck et al. 2011)	(0.89, 9, 0.0012)	(0.02, 9, 0.95)	(−0.12, 9, 0.77)
M22 (Marino et al. 2011)[a]	(−0.07, 21, 0.75)	(−0.13, 21, 0.56)	(0.21, 21, 0.36)
M80 (Cavallo et al. 2004)	(0.37, 8, 0.37)	(0.23, 10, 0.52)[b]	(0.66, 8, 0.075)[b]
M92 (Sneden et al. 2000b; Roederer & Sneden 2011)	(0.49, 16, 0.052)	(−0.02, 13, 0.95)	(−0.24, 12, 0.45)
NGC 1851 (Yong & Grundahl 2008)[a]	(0.50, 5, 0.40)	(0.41, 5, 0.49)	(0.52, 5, 0.37)
NGC 1851 (Carretta et al. 2010c)[a]	(0.87, 7, 0.0079)	(−0.89, 7, 0.0079)	(−0.80, 7, 0.030)
NGC 3201 (Gonzalez & Wallerstein 1998)	(0.57, 16, 0.021)	(−0.24, 16, 0.38)	(−0.37, 16, 0.16)
NGC 6752 (Cavallo et al. 2004)	(0.52, 7, 0.23)	(−0.83, 6, 0.043)[b]	(−0.71, 8, 0.05)[b]
NGC 6752 (Yong et al. 2005)	(−0.12, 17, 0.66)	(0.09, 17, 0.74)	(0.04, 38, 0.82)

Note. — Each set of data indicates r, N, and $P_c(r;N)$. If two element ratios of a parent distribution are uncorrelated, the probability that a random sample of N stars will yield a correlation coefficient $\geq |r|$ is given by $P_c(r;N)$. See, e.g., Bevington & Robinson (2003). Correlations between [La/Fe] and [Eu/Fe] are significant in several GCs, while correlations between [La/Fe] or [Eu/Fe] and [Na/Fe] are almost never significant.

[a] Using just the r-process-only stars
[b] [Al/Fe] instead of [Na/Fe]

In light of new observations of r-process abundance patterns in metal-poor field stars, we interpret the GC abundance patterns differently than previous investigators have. [Pb/Eu] or [Pb/Fe] ratios are more robust indicators of s-process nucleosynthesis at low metallicity than [Ba/Eu] or [La/Eu] ratios are (Roederer et al. 2010b). Previously, [Ba/Eu] or [La/Eu] ratios enhanced relative to their respective solar r-process ratios have been interpreted as evidence that a small amount of s-process material is mixed with a more dominant r-process contribution. In stars with low [Pb/Eu], we attribute the slightly higher [Ba/Eu] or [La/Eu] to intrinsic variations in the r-process abundance patterns themselves. In M5, M13, M15, M92, and NGC 6752, previous studies have found [Pb/Eu] ratios or upper limits consistent with only r-process nucleosynthesis (Yong et al. 2006, 2008; Sobeck et al. 2011; Roederer & Sneden 2011). GCs without Pb detections or upper limits have [La/Eu] ratios similar to those with low [Pb/Eu] ratios, so it is probable that all of these GCs have been enriched by r-process but not s-process material.

Only three n-capture species are routinely studied in metal-poor GCs: Ba II, La II, and Eu II. Smith (2008) has pointed out that GC stars on the AGB often have the highest [Ba II/Fe] and [Na I/Fe] ratios, and he tentatively attributed this phenomenon to self-enrichment. Others (Shetrone & Keane 2000; Ivans et al. 2001) have noted that this may be caused by shortcomings in the analysis that do not affect La II and Eu II, so we focus on identifying correlations between [La/Fe] and [Eu/Fe]. If abundances of other heavy elements derived from weak lines are available in the literature (e.g., [Nd/Fe]), we analyze them for confirmation. Correlation coefficients and probabilities are listed in Table 1. Six of the GCs (M3, M5, M13, M15, M92, and NGC 3201) show correlated [La/Fe] and [Eu/Fe] with less than a 5% probability that the ratios were drawn from an uncorrelated parent population. We now examine each of these GCs in more detail.

M15: r-process dispersion in M15 has been reported by many authors in stars on the red giant branch (Sneden et al. 1997, 2000a,b; Otsuki et al. 2006; Sobeck et al. 2011) and red horizontal branch (Preston et al. 2006; Sobeck et al. 2011). The dispersion spans a range of at least 0.5–0.6 dex in [Eu/Fe], though no more than 6 stars were studied in any given investigation. Sneden et al. (2000b) found a range of nearly 0.9 dex in [Ba/Fe] in 31 stars. It is no surprise to find a highly significant correlation between [La/Fe] and [Eu/Fe] in M15.

M92: The correlation between [La/Fe] and [Eu/Fe] is only moderately significant, but Roederer & Sneden (2011) demonstrated that each of these ratios also correlates strongly with [Ba/Fe] and [Ho/Fe], thus strengthening the claim. That study reported a range of more than 0.8 dex in [Eu/Fe], but typical uncertainties on each [Eu/Fe] measurement (0.2–0.4 dex) were significantly larger than in most studies (0.10–0.15 dex). Sneden et al. (2000b) found a range of more than 0.8 dex in [Ba/Fe] in 32 stars. We conclude that M92 exhibits significant r-process dispersion.

M5: The correlation between [La/Fe] and [Eu/Fe] is significant in the data of both Ivans et al. (2001) (25 stars) and Lai et al. (2011) (17 stars), and the Ivans et al. correlation becomes even stronger if one star (IV-4) with low S/N is excluded. Each of the heavy n-capture elements (Ba, La, Ce, Nd, Sm, and Eu) studied in at least 10 stars spans a range of 0.25–0.45 dex. M5 also exhibits a clear signature of r-process dispersion.

NGC 3201: The correlation between [La/Fe] and [Eu/Fe] is significant. Gonzalez & Wallerstein (1998) found a range of nearly 0.7 dex in [Eu/Fe] from 17 stars, nearly 0.7 dex in [La/Fe], nearly 0.5 dex in [Ba/Fe], and

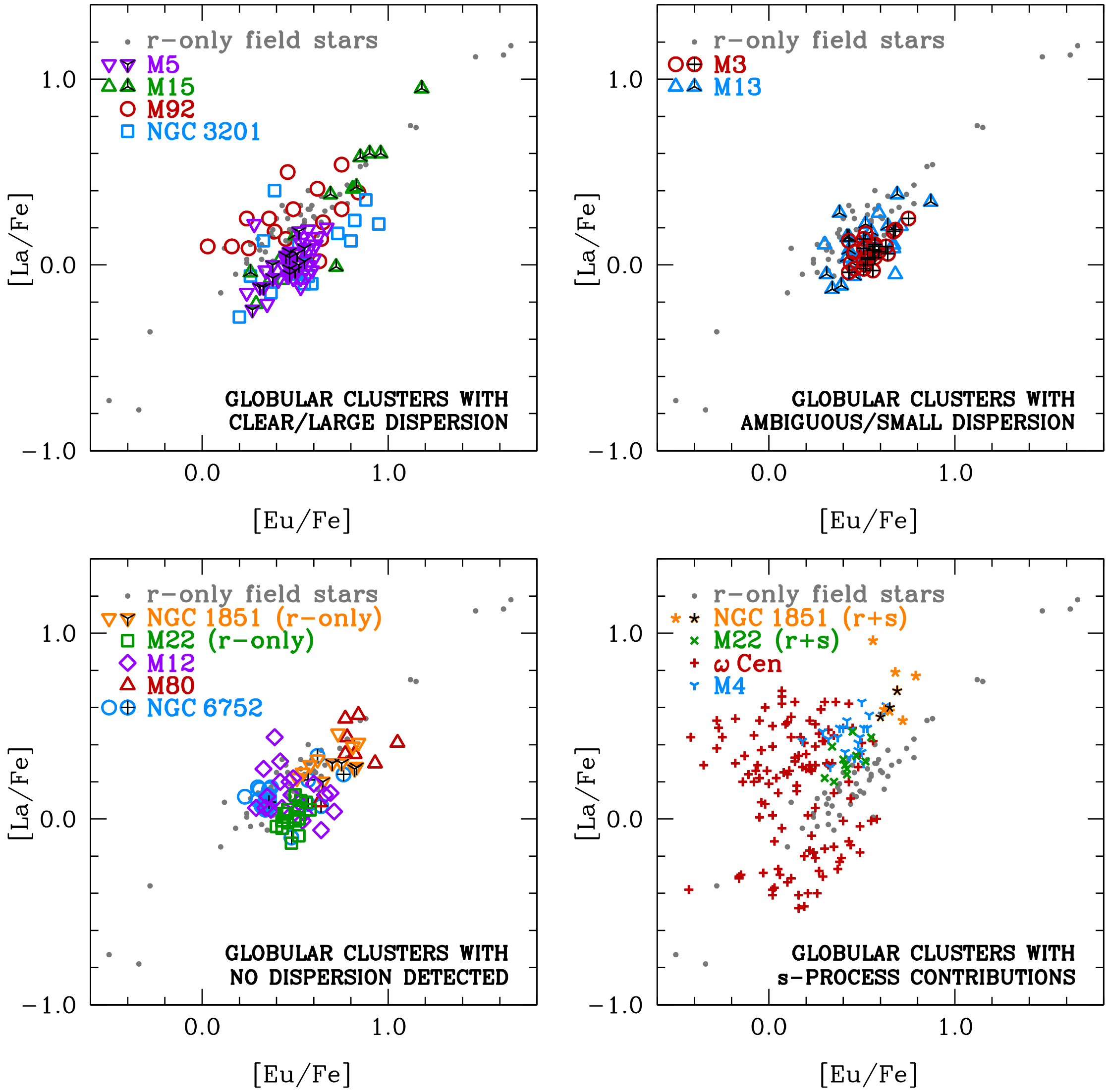

FIG. 1.— The [La/Fe] and [Eu/Fe] ratios in GCs that exhibit clear evidence for *r*-process dispersion (*top left*), those that exhibit ambiguous evidence (*top right*), those where no *r*-process dispersion has been detected (*bottom left*), and those with clear evidence for *s*-process enrichment (*bottom right*). Data are taken from the following sources: M3 and M13, Sneden et al. (2004) (crossed) and Cohen & Meléndez (2005); M4, Ivans et al. (1999); M5, Ivans et al. (2001) and Lai et al. (2011) (crossed); M12, Johnson & Pilachowski (2006); M15, Otsuki et al. (2006) and Sobeck et al. (2011) (crossed); M22, Marino et al. (2011); M80, Cavallo et al. (2004); M92, Roederer & Sneden (2011); NGC 1851, Yong & Grundahl (2008) (crossed) and Carretta et al. (2010c); NGC 3201, Gonzalez & Wallerstein (1998); NGC 6752, Cavallo et al. (2004) (crossed) and Yong et al. (2005); ω Cen, Johnson & Pilachowski (2010); *r*-process field stars, Roederer et al. (2010b). Stars that are common to multiple studies of the same GC have only been displayed once.

more than 0.4 dex in [Ce/Fe]. The correlation between [Eu/Fe] and [Ba/Fe] is also significant, and the correlation between [La/Fe] and [Ba/Fe] is suggestive but not statistically significant. The large metallicity spread found by Gonzalez & Wallerstein has not been reproduced (Covey et al. 2003; Carretta et al. 2009), but the explanations for the discrepancy suggested by Covey et al. should not significantly affect La II or Eu II. These data suggest that an *r*-process dispersion is present in NGC 3201.

Abundances in these four GCs are shown in the top left panel of Figure 1. A set of metal-poor field stars that exhibit no evidence of *s*-process enrichment by virtue of their low [Pb/Eu] ratios are shown for comparison. The GC data overlay the same region of the diagram as the field stars. [La/Eu] is constant in these GC stars as both elements vary together, and the ratio, [La/Eu] $= -0.4 \pm 0.2$, is consistent with that observed in metal-poor field stars with $0.0 <$ [Eu/Fe] $< +1.0$. The larger uncertainties in M92 are evident, and there may be 1 or 2 stars in M15 and NGC 3201 that deviate from the main concentration. These GCs show clear evidence for star-to-star *r*-process dispersion relative to Fe.

M3 and **M13**: Sneden et al. (2004) and Cohen & Meléndez (2005) studied a number of stars in this pair of GCs, shown in the upper right panel of Figure 1. The [La/Fe] and [Eu/Fe] ratios in these two studies give conflicting results. Correlations derived from the Sneden et al. data are highly significant, but the Cohen and Meléndez data do not show any significant correlation; statistics for the combined samples produce a highly significant result for M3 but not M13. The

Sneden et al. samples are larger for both GCs. The ranges spanned by [Ba/Fe] and [La/Fe] are similar in both investigations. Excluding the anomalous star B4.4 in M3, [Eu/Fe] spans 0.3 dex in M3 in the 22 stars of Sneden et al. but only 0.1 dex in the 8 stars of Cohen and Meléndez. A spurious correlation could arise from poor estimates of the stellar parameters; if so, we would expect correlations between pairs of other singly-ionized elements such as Sc II and Ti II. There is no such correlation [$(r,\ N,\ P_c) = (-0.03,\ 20,\ 0.89)$] in the M3 data of Sneden et al., who did not publish Sc II or Ti II abundances for M13. We attribute the discrepancy to the different sample sizes and conclude that M3 and M13 probably exhibit r-process dispersion.

Three other GCs in our sample, M12, M80, and NGC 6752, show no significant correlation between [La/Fe] and [Eu/Fe]. The abundances of M22 and NGC 1851 show a bimodal distribution (Yong & Grundahl 2008; Marino et al. 2009, 2011; Carretta et al. 2010c), which may suggest that they formed under unusual circumstances (e.g., the merger of two separate GCs). In M22, the separation is clear in, e.g., [La/Fe] and [La/Eu] (Marino et al. 2011). The separation in NGC 1851 is less obvious, and we make an approximate division at $\mathrm{[La/Fe]_r} < 0.50$ dex. Based on the available observations—illustrated in the lower left panel of Figure 1—M12, M80, NGC 6752 and the r-process-only population in M22 lack r-process dispersion. The r-process-only population in NGC 1851 shows a correlation between [La/Fe] and [Eu/Fe] based on 7 stars from Carretta et al. (2010c), while the 5 stars of Yong & Grundahl (2008) show no such correlation; combining these samples produces an ambiguous result [$(r,\ N,\ P_c) = (0.52,\ 12,\ 0.084)$]. Additional data may help resolve the matter.

The lower right panel of Figure 1 demonstrates that r-process dispersion is clearly distinguishable from s-process enrichment. Stars in M4 (Ivans et al. 1999; Yong et al. 2008) and ω Cen (e.g., Smith et al. 2000) are enhanced in s-process material, and this increases [La/Eu] substantially. The same effect is observed in the $r + s$ populations of M22 and NGC 1851. Except for a few stars in ω Cen that exhibit an r-process-only signature, the rest are clearly distinct from the r-process-only field stars. The dispersion in M3, M5, M13, M15, M92, and NGC 3201 is unrelated to s-process enrichment.

Finally, we examine whether r-process dispersion correlates with the classical light element dispersion. Using [Na/Fe] as a proxy for the light elements, we search for correlations between [Na/Fe] and either [La/Fe] or [Eu/Fe]. As Table 1 shows, there is no correlation in nearly all cases. In NGC 6752 a significant correlation is present in the 6 and 8 stars of Cavallo et al. (2004), but employing the 17 and 38 stars of Yong et al. (2005) reveals no correlation. [La/Fe] and [Na/Fe] are anticorrelated in the M13 data of Sneden et al. (2004), but this is the opposite of what would be expected if Na production is accompanied by s-process nucleosynthesis. [Eu/Fe] and [Na/Fe] show no significant correlation in M13, so we conclude that the [La/Fe] versus [Na/Fe] anticorrelation is not real. In these 11 GCs, the r-process dispersion is independent of the light element dispersion.

4. DISCUSSION

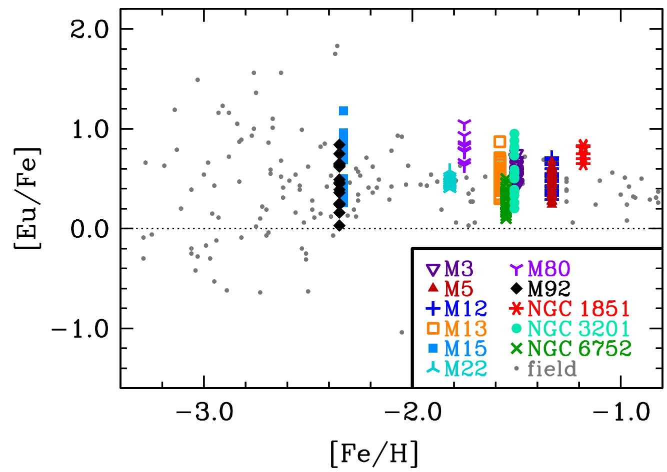

Fig. 2.— Comparison of [Eu/Fe] between metal-poor field stars and the 11 GCs discussed in Section 3. All GC abundances have been compressed to each GC's mean metallicity (on the Carretta et al. 2009 scale). Just the r-process-only stars in M22 and NGC 1851 have been displayed here. Field star abundances are taken from the recent literature (Fulbright 2000; Johnson 2002; Honda et al. 2004; Barklem et al. 2005; François et al. 2007; Lai et al. 2008; Roederer et al. 2010a).

All of these GCs are metal-poor (by selection) and older than $\approx$ 11 Gyr. We consider whether the GCs that do show r-process dispersion and those that do not have differences in their structural (Harris 1996) or kinematic (Dinescu et al. 1999; Casetti-Dinescu et al. 2007) properties, horizontal branch morphologies (Lee 1990), or RR Lyr types (Clement et al. 2001). We find no differences except that the GCs with r-process dispersion—including M3 and M13—have larger apogalactic radii (10–35 kpc) than those that do not (3–6 kpc). (M22 and NGC 1851 have large apogalactic radii—9.3 and 30 kpc, respectively—but as noted previously their formation histories may be more complex.) This may indicate that the distribution of r-process material reflects properties (e.g., mass, formation locations or timescales) of the giant molecular clouds (GMCs) in which the GCs formed (cf., e.g., Carretta et al. 2010a).

D'Orazi et al. (2010) presented [Ba/Fe] dispersion (root mean squared, rms) values for 15 GCs, including 4 in our sample. M5, M15, and NGC 3201 have [Ba/Fe] rms values of 0.210, 0.412, and 0.267, respectively, while NGC 6752 has an rms of 0.176. This suggests that ≈ 0.2 may represent the detectable r-process dispersion threshold. Based on this simple-minded discriminant (and ignoring GCs with $\mathrm{[Fe/H]} > -1.0$ or $\mathrm{[Ba/Fe]} > +0.4$, which may contain significant s-process material), from the D'Orazi et al. data we predict that M10, M55, M68, and NGC 6397 may exhibit r-process dispersion, while M30 and M79 may not.

As has been discussed in detail elsewhere (e.g., Gratton et al. 2004), the heavy element abundances in metal-poor GCs and field stars are very similar.[2] We illustrate this fact in Figure 2 for the 11 GCs analyzed in Section 3. The mean [Eu/Fe] for each of these GCs is $+0.5 \pm 0.3$, which is consistent with the majority of field stars with $-2.5 < \mathrm{[Fe/H]} < -1.0$. The pres-

[2] Figure 12 of Roederer et al. (2010b) indicates that GCs have ratios of light to heavy n-capture elements, e.g., [Y/Eu], similar to those found in field stars.

ence of r-process dispersion in some GCs is not inconsistent with the idea that GCs were once much more massive (e.g., D'Ercole et al. 2008; Carretta et al. 2010a; Gratton & Carretta 2010) and lost a significant fraction of their first generation stars (i.e., those with undepleted O and unenhanced Na) to the stellar halo (cf. Martell & Grebel 2010).

Nearly all metal-poor field stars contain detectable amounts of r-process material, and all GC stars studied to date have detections or uninteresting upper limits for these elements. Roederer et al. (2010b) uncovered a range of [La/Eu] ratios (spanning at least 0.5 dex) in field stars with low [Pb/Eu] (i.e., lacking s-process material). This suggests that the variations are intrinsic to the r-process yields, since dilution of material from identical but rare r-process events cannot alone account for a range of [La/Eu]. In GCs, homogeneous Fe-group abundances and inhomogeneous r-process abundances relative to Fe could indicate that r-process material is not produced by every SN or is unevenly dispersed (e.g., concentrated in jets; Otsuki et al. 2006). Alternatively, r-process material may have been injected into the gas shortly before star formation, thereby limiting its homogenization (Sneden et al. 1997; Otsuki et al.). Either way, r-process material must be present but incompletely mixed into the gas from which some GCs form.

Expectations from O/Ne/Mg-core SN physics (e.g., Wheeler et al. 1998; Wanajo et al. 2003) predict that low-mass ($\sim$ 8–10 $M_\odot$) Type II SNe are a dominant source of r-process material but produce little or no Fe-group material. If so, they would be among the last sources contributing to the chemical inventory of the GC ISM before massive AGB stars undergo significant mass loss. Yet, some (unidentified) mechanism(s) must exist to prevent r-process material from fully homogenizing until other sources have polluted the GC ISM. Otherwise we would observe r-process dispersion only in first generation stars with undepleted O and unenhanced Na; later generations would have homogeneous r-process abundances, which is not observed (Smith 2008). If the dynamical crossing time of the GMCs from which GCs form is comparable to the mixing timescale (e.g., McKee & Ostriker 2007 and references therein; see also Carretta et al. 2010b), we can estimate a lower limit for the timescale of chemical homogenization. 8–10 $M_\odot$ stars have lifetimes of a few ($\lesssim$ 10) Myr, comparable to the crossing times ($\sim$ 5–20 Myr) of 10^5–10^7 $M_\odot$ GMCs. If unmixed r-process material is preserved for several tens of Myr (e.g., in the atmospheres of main sequence stars, Gratton & Carretta 2010) before being returned into the ISM, it could later become diluted with the ejecta of high-mass AGB stars that may produce the familiar O-Na and Mg-Al anti-correlations in subsequent stellar generations.

Present-day GC masses are large enough to ensure complete sampling (on average) of a Salpeter IMF ($M > 10^5 M_\odot$), and their initial masses would certainly have been so, although star formation in proto-GCs clearly extended longer than a single burst. This may help explain why the mean ratios of elements produced in Type II SNe are generally constant from one GC to the next. (Stochastically sampling the IMF could significantly affect the abundances in lower-mass systems like the ultra-faint dwarf galaxies; e.g., Koch et al. 2008, Feltzing et al. 2009, Simon et al. 2010.) Adopting the range of r-process yields predicted by the high entropy neutrino wind simulations of Farouqi et al. (2010) (10^{-6} to 10^{-4} $M_\odot$ per event), assuming $M_{\rm r,\ total} \sim 10^4 \times M_{\rm Eu}$, and assuming a star formation efficiency of 10% in GCs with initial masses $\sim$ 10 times larger than their present mass predicts a lower limit of $\sim$ 10^2–10^4 SNe to produce the observed GC r-process enrichment levels. Alternatively we can use the observed GC r-process abundances to derive a lower limit on the fraction of 8–10 $M_\odot$ SNe that produce an r-process. Assuming the maximum r-process yields from Farouqi et al. and assuming that all r-process material is incorporated into stars, we derive a lower limit of $\sim$ 1/7 SNe with initial masses 8–10 $M_\odot$ should produce an r-process. Relaxing these assumptions would increase this fraction substantially.

The data currently available indicate that r-process dispersion may be a common but not ubiquitous characteristic of metal-poor GCs. These data are inadequate to discern details such as the fraction of GCs with dispersion or the range and distribution of r-process abundances within each GC. Whatever the explanation, an understanding of what parameter(s) control the distribution of r-process material in GCs is greatly desired.

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